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THE CLASSIFICATION OF WIND SHEARS FROM THE POINT OF VIEW OF AERODYNAMICS AND FLIGHT MECHANICS

Dr. Fritz Seidler, Gunter Hensel

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16. Abstract

A study of international statistical data shows that in about three quarters of all serious accidents which occurred with jet propelled airliners wind shear was either one of the main causes of the accident or represented a major contributory cause. The present article is concerned with wind shear related problems. The necessity of a use of different concepts, definitions, and divisions is explained, and the concepts and definitions required for the division of wind and wind shear into different categories is discussed. A description of the context between meteorological and aerodynamics-flight mechanics concepts, definitions, and divisions is also provided. Attention is given to wind and wind components, general characteristics of wind shear and the meteorological terms, the basic types of wind shear for aerodynamics-flight mechanics investigations, special types of wind shear for aerodynamics-flight mechanics investigations, and possibilities regarding a change of the wind component.

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The phenomenon of wind shear has become increasingly important in the last ten to fifteen years, especially with regard to the massive use of turbine-jet powered commercial aircraft. TIZL is publishing the following article which pertains to the classification of wind shear from the viewpoint of aerodynamics and flight mechanics. The authors will report on the effects of wind shear in a future edition of this journal.

Editors, TIZL

1. Objective

International statistics confirm that wind shear is a primary cause or a major contributory cause in about three-fourths of all serious aircraft accidents involving jet propelled commercial aircraft during take-off or landing near an airport. This finding makes clear how important it is to analyze the effects of wind shear on changes in flight status and the flight path of the aircraft, in order to eliminate this danger through suitable measures and thus to further improve flight safety. In particular, it is important to familiarize the aircraft crew and those involved in air traffic control with the aerodynamic and flight-mechanical relationships in air layers with wind shear and to enable them to take proper and informed actions in such situations.

The present article deals with one aspect of wind shear and has the following objectives:

-to explain that differing terms, definitions and classifications are needed with regard to wind and wind shear, from the meteorological point of view and under consideration of aerodynamics and flight mechanics;

-to classify wind and wind shear with regard to aerodynamics and flight-mechanics and to clarify the terms and definitions necessary for this, and

-to elucidate the relationships between the meteorological and aerodynamic/flight-mechanics terms, definitions and classifications.

2. Wind and Wind Components

Wind is the motion or flow of atmospheric air over the earth, which is viewed as stationary. This motion is stated as the vector of wind velocity $\vec{u}$, which has magnitude and direction. In the general case, the wind vector $\vec{u}$ is sloped upward or downward to the horizon, so that it breaks down into a horizontal component uH and a vertical component uV (fig. 1). If the vertical component or vertical wind, as illustrated in fig. 1, is directed from bottom to top, then we call this lift; if the vertical wind is directed from top to bottom, then this is called down current. In meteorology, to characterize the horizontal component or the horizontal wind uH, the amount denoting the wind velocity and the azimuth angle Xw denoting the wind direction are used, and it is common to relate the azimuth angle to the direction from which the wind is blowing. To study the aerodynamic effects of wind on the aircraft, the meteorological data alone are not sufficient, and it is necessary to introduce other terms which are tailored to this purpose and which simplify it. The purpose of aerodynamic/flight-mechanical investigations in connection with air flows in the

atmosphere, is to determine how the forces of air, the flight path, flight performance, flight properties and the operating behavior of the aircraft are affected and changed by wind. This influence depends on how the size and direction of the wind vector $\vec{u}$ behave with regard to the size and direction of the flight velocity vector $\vec{v}$ of the aircraft.

For this reason, the horizontal wind uH breaks down into two other components, and the horizontal component vH of the flight velocity vector $\vec{v}$ serves as reference direction (fig. 2). The

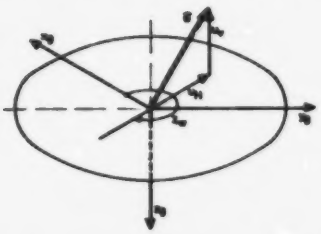

Fig. 1: Breakdown of the Wind Vector $\vec{u}$ into a Horizontal Component uH and a Vertical Component uV.

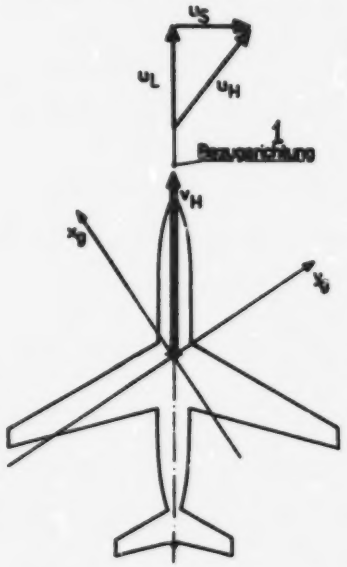

Fig. 2: Breakdown of the Horizontal Component uH of the Wind Vector $\vec{u}$ into a Longitudinal wind Component uL and an Azimuth wind Component uS.

Key: 1-reference direction

vector of flight velocity $\vec{v}$ indicates the motion of the aircraft to the surrounding air and is broken down like the wind vector $\vec{u}$, into a horizontal- and a vertical component, called vH or vV (or

W), respectively. The component of horizontal wind uH acting parallel to the horizontal component vH of the flight velocity, is the longitudinal wind component or the longitudinal wind uL, and the component of uH acting perpendicular to vH, is called the side wind component or side wind uS. Figure 3 shows a breakdown of the wind vector $\vec{u}$ into all its components for an aircraft in thrust-free horizontal flight in the direction of the fixed ground axis Xg with a zero angle of approach. This particularly simple, special case was selected in order to clearly show the essential. The longitudinal wind can be tailwind (same direction as vH; fig. 3a) or headwind (opposite direction to vH; fig. 3b), while the side wind can come from left (fig. 3a) or right (fig. 3b).

The component breakdown of the wind vector $\vec{u}$ into longitudinal wind uL, side wind uS and vertical wind uV, is useful for aerodynamic and flight-mechanics considerations, since these components act quite differently on the aircraft and thus require differing countermeasures. In the individual, practical cases, all components will not always exist simultaneously. It frequently happens that the vertical component of the wind vector of the flight velocity vector are zero (uV = w = 0; horizontal flight in horizontal wind). The two possibilities of the wind components (tail- or headwind; side wind from left or right; lift or down-wind) can also differ by positive or negative signs.

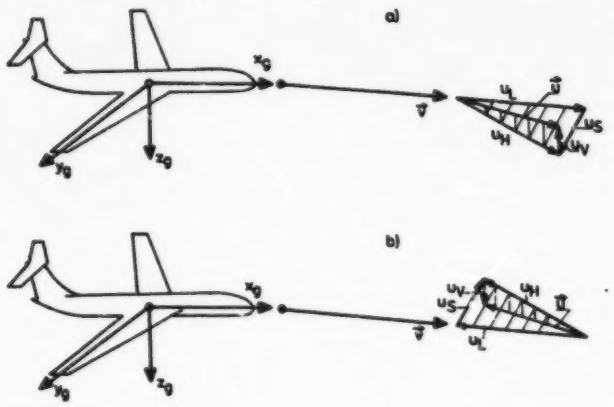

Fig. 3: Breakdown of the Wind Vector $\vec{u}$ into Longitudinal Wind uS and Vertical Wind uV on an aircraft in non-thrust horizontal flight in the direction of the fixed ground axis Xg with zero angle of approach.
a) uL - tailwind, uS - side wind from left, uV - upwind
b) uL - headwind, uS - side wind from right, uV - down wind

3. Wind Shear and Types of Wind Shear

3.1 General Information and Meteorological Designations

Shear flows are generally those where the immediately neighboring layers of the flowing medium are moving at differing velocities, so that these layers push against each other and tangential forces occur between them, which are also called thrust or shear forces (fig. 4). The best-known shear flows in aircraft aerodynamics are the flows in the boundary layers generated due to the viscosity of air in the direct vicinity of the surface of moving bodies and they are the cause for the frictional resistance. The concept of shear was taken from the mechanics of solids and from the cutting action of shear. Wind shear or shear winds are shear flows of air in the atmosphere. They are characterized by the fact that directly neighboring layers are moving

at different velocities, that the wind velocity vector $\vec{u}$ changes from layer to layer. The wind velocity or wind vector $\vec{u}$ is thus a function of location and can also be a function of time. Both the value and the direction of the wind vector can change. Therefore, in meteorology, a distinction is made between wind velocity shear or velocity shear, and wind direction shear or direction shear. The measure for the velocity shear is the velocity gradient, the difference in wind velocity related to a length (e.g meter/second per meter). The measure for direction shear is the difference in wind direction relative to a length (e.g. degrees per 100 m).

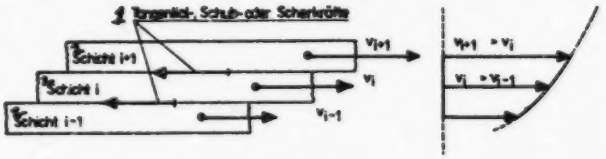

Figure 4. Schematic Illustration of Shear Flow

Key: 1-tangential, thrust or shear forces 2-layer

Other terms used in meteorology pertaining to wind shear are horizontal and vertical wind shear, and both of these can be either velocity or direction shear. In a horizontal wind shear, the wind velocity (horizontal velocity shear) and/or the wind direction (horizontal direction shear) change along a horizontally placed reference length, while in a vertical wind shear, the wind velocity (vertical velocity shear) and/or the wind direction (vertical direction shear) change along a vertically placed reference length or with altitude.

3.2 Basic Types of Wind Shear for Aerodynamic/Flight-Mechanics Investigations

For wind shear pertaining to aerodynamic considerations, the shear is related to the defined components of longitudinal wind uL, side wind uS and vertical wind uV, since the influence of wind shear on the aircraft depends on its direction relative to the flight velocity vector $\vec{V}$. In this manner, we obtain the equations:

longitudinal wind shear: $u_{L,s} = \frac{du_L}{dl}$ (1a)

side wind shear: $u_{s,s} = \frac{du_s}{dl}$ (2a)

vertical wind shear $u_{v,s} = \frac{du_v}{dl}$ (3a)

which denote the change in velocity of the longitudinal, side and vertical wind with a general length coordinate l. In many practical cases, one can assume a nearly linear velocity change, so that:

$$u_{L,s} = \frac{\Delta u_L}{\Delta l} = \text{const.}\ (1b), u_{s,s} = \frac{\Delta u_s}{\Delta l} = \text{const.}\ (2b) \text{ and}$$
$$u_{v,s} = \frac{\Delta u_v}{\Delta l} = \text{const.}\ (3b)$$

The length coordinate in practice, can be either the flight path s or the altitude H. Thus, the shears are the change in velocity within a path segment Δs or within an altitude segment ΔH or the velocity gradients relative to the path or altitude:

$$u_{L,s} = \frac{\Delta u_L}{\Delta s}\ (1c) \quad \text{or} \quad u_{L,s} = \frac{\Delta u_L}{\Delta H}\ (1d),$$

$$u_{s,s} = \frac{\Delta u_s}{\Delta s}\ (2c) \quad \text{or} \quad u_{s,s} = \frac{\Delta u_s}{\Delta H}\ (2d)$$

$$u_{v,s} = \frac{\Delta u_v}{\Delta s}\ (3c) \quad \text{or} \quad u_{v,s} = \frac{\Delta u_v}{\Delta H}\ (3d).$$

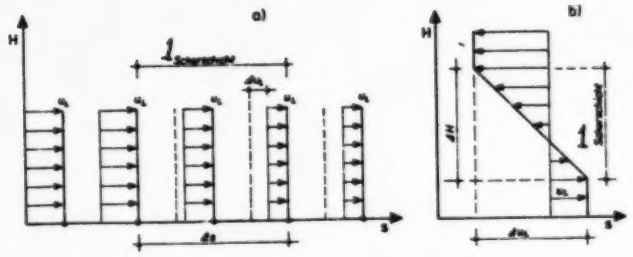

Fig. 5: Schematic of Linear Longitudinal Wind Shear.
a) Linear longitudinal wind shear vs. the path per eq. (1c) with decreasing longitudinal wind along the path
b) Linear longitudinal wind shear vs. the altitude per eq. (1d) with change in sign

Key: 1-shear layer

The wind components uL, uS and uV can increase or decrease along the path s or with altitude H, which is indicated by a positive or negative sign of the wind shears or velocity gradients uL,S, uS,S and uV,S. The path segment Δs or altitude segment ΔH in which the longitudinal, side or vertical wind changes, is called the shear layer. From the number of possible cases, figures 5 to 7 show a typical longitudinal, side and vertical wind shear along path s (figure section a) and over the altitude H (figure section b), and linear changes in longitudinal, side and vertical wind (uL, uS, uV) with constant velocity gradients (uL,S, uS,S, uV,S) are assumed. In front of or behind, or under or over the shear layer, the longitudinal, side and vertical wind is constant (uL = const., uS = const., uV = const.) and the velocity gradients are zero (uL,S = uS,S = uV,S = 0). The constant value of longitudinal, side or vertical wind can also be zero, as is the case in fig. 7a for vertical wind behind the shear layer. The

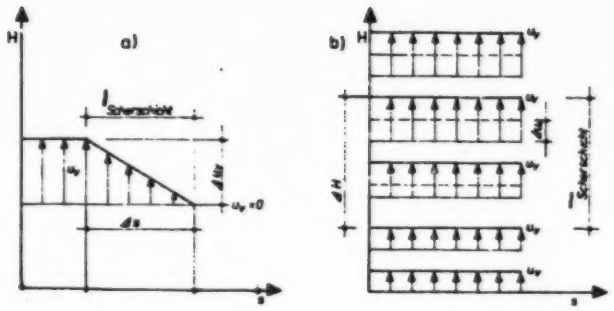

Fig. 6: Schematic Illustration of Linear Side Wind Shear
a) Linear side wind shear vs. the path per eq. (2c) with decreasing side wind from left, change in sign, and increasing side wind right along the path
b) Linear side wind shear vs. the altitude per eq. (2d) with increasing side wind from left with increasing altitude

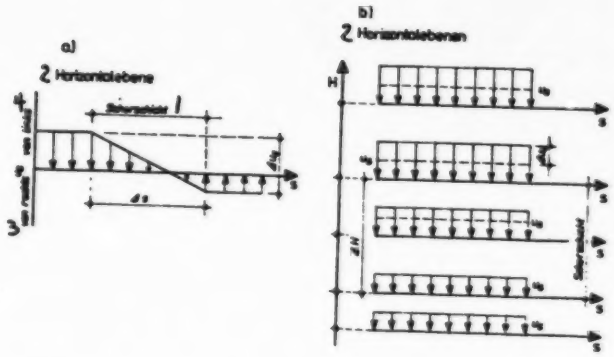

Fig. 7: Schematic Illustration of Linear Vertical Wind Shear
a) Linear vertical wind shear vs. the path per eq. (3c) with decreasing upwind along the path to uV = 0
b) Linear vertical wind shear vs. altitude per eq. (3d) with increasing upwind with increasing altitude

Key: 1-shear layer 2-horizontal plane 3-from right 4-from left

wind components uL, uS and uV can change direction or sign in the shear layer. Figures 5b and 6a show examples of this.

In figures 5 to 7, only one type of wind shear is shown. In practice, naturally several shear types can occur simultaneously and overlap. For example, the same wind components can change both along the path and also with altitude, and changes in two or three different wind components can exist along the path or along the altitude.

3.3 Special Wind Shear Types for Aerodynamic Investigations

From a comparison of the terms and definitions introduced in aerodynamics and flight mechanics in connection with wind and wind shear, it follows that the flow field of wind in meteorology is established relative to the earth and in aerodynamics and flight mechanics, relative to the motion of the aircraft. How a wind field described relative to the earth and by the terms of meteorology will affect the aerodynamics and flight mechanics of an aircraft, depends greatly on the flight path of the aircraft through the wind field. This factor naturally also applies when shear layers are present in the wind field. For these cases, it must be specified that the aerodynamic and flight-mechanics effects of a wind shear on an aircraft depend significantly on what flight path the aircraft takes through the shear layer.

Figures 5 to 7 presume that the aircraft is moving in the direction of the positive path coordinate s. In the horizontal shear layers along the path (figure section a), the shear effect is independent of whether the aircraft is moving through the shear layer in horizontal, ascent or descent flight. The type of change of the particular wind component is the same and independent of the slope of the flight path to the horizon. Thus, when flying through the shear layer in horizontal, ascending or descending flight in fig. 5a, the tailwind decreases; in fig. 6a the side wind decreases from the left and then increases from the right, and in fig. 7a, the upwind decreases. These relationships reverse when the horizontal shear layer (figs. 5a and 7a) is transited in

the opposite direction. Then the headwind (fig. 5a) and upwind (lift) (fig. 7a) increase. In the case illustrated in fig. 6a, the transit direction has no effect on the type of change of the side wind. When transiting from right to left, first the side wind decreases from the left and then increases from the right.

There are fundamentally different relationships in the altitude shear layers (figure section b). We find that transiting a vertical shear layer in horizontal flight has no effect on the aircraft, since the particular wind component does not change along the flight path. Thus, depending on whether the shear layer is transited in the lower or upper region (fig. 5b), either the tailwind or headwind, the side wind from left (fig. 6b) or the upwind (fig. 7b) remains constant. The effect of the shear layer on the aircraft occurs in an ascending or descending flight, where the type of change of the particular wind component in an ascent is opposite to that of a descent. Thus, when transiting the shear layer in an ascent (fig. 5b) from bottom to top, first the tailwind decreases and then the headwind increases, and when transiting the shear layer in a descent from top to bottom, first the headwind decreases and then the tailwind increases. In accord with fig. 6b, the side wind increases from the left in an ascent, and decreases in a descent, and per fig. 7b, the upwind increases in an ascent, and decreases in a descent.

When flying through the vertical shear layers in the opposite direction from right to left, nothing changes in the cases shown in figs. 6b and 7b, compared to flying through from left to right. In the vertical shear layer (fig. 5b), when transiting from right to left in horizontal flight, the constant tailwind and headwind are reversed and in an ascent and descent, the changes in longitudinal wind are reversed. Thus, in horizontal flight a constant headwind is encountered in the lower, and constant tailwind in the upper part of the shear layer. In an ascent, first the headwind decreases and then the tailwind increases, and in a descent, after an initial decrease in headwind, the tailwind becomes larger.

It is obvious that the different changes in wind components depending on flight path within the shear layer, have different effects on the aircraft. From the examples illustrated in figures 5 to 7 if follows that for every basic type of wind shear (longitudinal, side and vertical shear), there exist two potential changes in the particular wind component, depending on the flight path. Terms have naturally been devised for these specific types of change in wind component. For the longitudinal wind shear, this is the tailwind shear and headwind shear; for side wind shear, the terms are left wind shear and right wind shear, and for vertical wind shear, the upwind (lift) shear and downwind shear.

The definitions of these specific types of wind shear and corresponding examples arising from figs. 5 to 7, are presented in table 1.

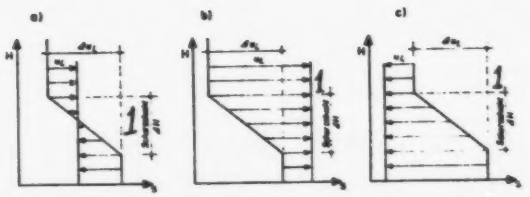

Fig. 8: Schematic Illustration of Three Possibilities for a Tailwind or Headwind Shear for an Aircraft Transiting the Vertical Shear Layers in Direction of the Positive s-Axis in an Ascent of Descent

a) Ascent: Decrease in headwind and increase in tailwind; tailwind shear
   Descent: Decrease in tailwind and increase in headwind; headwind shear
b) Ascent: Increase in tailwind; tailwind shear
   Descent: Decrease in tailwind ; headwind shear
c) Ascent: Decrease in headwind; tailwind shear
   Descent: Increase in headwind; headwind shear

Key: 1-shear layer

The increase of a wind component in one direction has the same effect on the aircraft as a decrease in the same wind component in the opposite direction. For example, an increase in tailwind has the same effect as a decrease in headwind. Therefore, every specific type of wind shear is characterized by two properties. These properties, for the example of tailwind shear, are the decrease in headwind and the increase in tailwind. The decrease in wind components in the opposing direction (see definitions in table 1) is stated before the increase in the direction used to state the shear, since--as we see from figs. 5b and 6a--a continual transition is possible in this sequence.

3.4 Possible Changes in Wind Components in a Specific Shear Type

When transiting the shear layers, the direction of the changing wind components can reverse or remain in one of the two direction regions. Therefore, the definitions (table 1) contain the statement "...and/or...". Figure 8 shows the three possibilities of longitudinal wind shear with vertical shear layers. These shear layers produce tailwind shear for aircraft in an ascent, and headwind shear for aircraft in a descent in the direction of the positive s-axis. For tailwind shear in an ascent, fig. 8a shows the case with direction change where first, a decrease in the headwind and then an increase in tailwind occurs, so that the word "...and..." appears in the definition for tailwind shear (table 1). In figure 8b, the increase in tailwind is represented and thus the second part of the definition per table 1 ("...or increase in tailwind") applies exclusively to the term "tailwind shear".

Finally, in fig. 8c we are dealing with a simple decrease in headwind, corresponding to the first part of the definition in table 1 ("decrease in headwind...").

With regard to the headwind shear in an ascent, fig. 8a also shows the case with change of direction, where initially a decrease in tailwind, and then an increase in headwind occurs ("...and..." in the definition). However, in fig. 8b we see a simple decrease in tailwind (first part of definition) and in fig. 8c, a simple increase in headwind (second part of definition). In the three possibilities for one and the same wind shear type, the

aerodynamic and flight-mechanical influences on the aircraft are equivalent, so that the same designation is justified. However, the influences in a tailwind and headwind shear are fundamentally different. Reference was made to special cases, where the particular wind component is zero before beginning or after the end of the shear layer (fig. 7a). Another group of special cases (vertical shear layers at low altitude) is characterized by the fact that the shear layer extends down to the ground and an altitude sector of constant wind components does not exist between the lower boundary of the shear layer and the ground. Such special cases are illustrated for longitudinal wind shear in figure 9, which also shows the dependence of the specific type of wind shear on the flight path. From the possibilities shown in figs. 9a to 9c for the basic distribution of longitudinal wind in the vertical shear layers, there result three different headwind shears (fig. 9d) for landing aircraft moving in the direction of the positive s-axis in a descent, and three different tailwind shears (fig. 9e) for aircraft taking off in the direction of the positive s-axis and transiting the shear layers in an ascent.

3.5 Wavelength, Gradient and Altitude of Wind Shear

The effect of wind shear on an aircraft also depends on the wavelength of the wind shear and the gradient of wind velocity--besides the factors treated in sections 3.2 and 3.3. Wind shear present in the atmosphere covers very large ranges of wavelength and gradient, so that their effects dependent on these quantities, can be quite different on the aircraft.

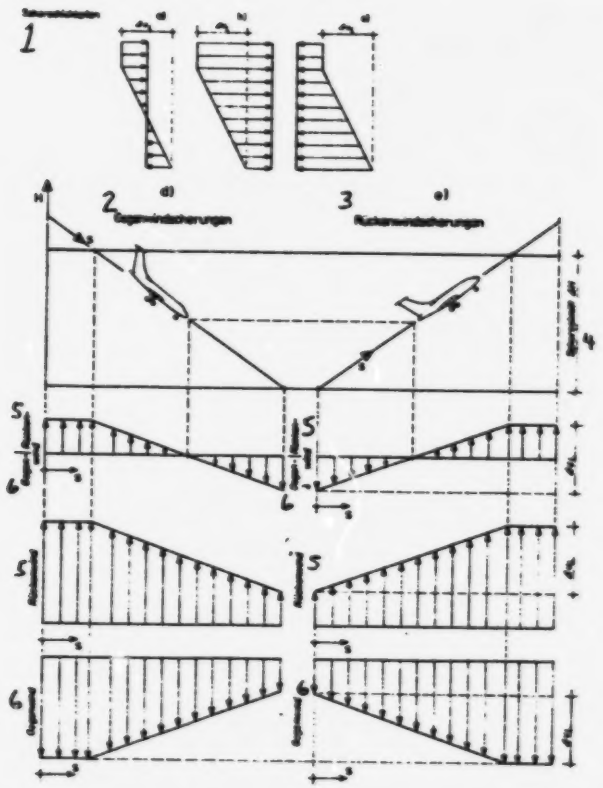

Fig. 9: Illustration of Longitudinal Wind Shear with Shear Layers extending down to the ground.
a) Shear layer with change in direction of longitudinal wind
b) Shear layer with only tailwind
c) Shear layer with only headwind
d) Headwind shear for a descending aircraft transiting the shear layer
d1) to a): Decrease in tailwind and increase in headwind
d2) to b): Decrease in tailwind
d3) to c): Increase in headwind
e) Tailwind shear for an ascending aircraft transiting the shear layer
e1) to a): Decrease in headwind and increase in tailwind
e2) to b): Increase in tailwind
e3) to c): Decrease in headwind

Key: 1-types of wind shear 2-headwind shear 3-tailwind shear 4-shear cut 5-tailwind 6-headwind

According to their wavelength and wind velocity gradients and resultant, characteristic effects on aircraft, wind shear is classified into three groups (table 2). Group 1 wind shears with small to very small wavelengths and very large gradients at short

to very short distances (a few meters) are known as gusts and cause short-term accelerations of the aircraft which can assume large to very large values for large flight and gust velocities. If gusts are present in the atmosphere, then we speak of gusty or turbulent air, gustiness or turbulence. The concept of wind shear is rarely used in connection with gusts, although this is a special type of wind shear. The accelerations on aircraft caused by gusts act via the load multiple on the strength integrity of the aircraft and on the comfort of passengers. When sizing the strength integrity therefore, the gust load multiples must be taken into account. But the gusts have only a minor effect on flight path, even if they generate large accelerations, because of their high frequency (short-term effect) and the inertia of the aircraft, so that this group of wind shear represents no immediate danger if the strength level of the aircraft is sufficient.

Also non-dangerous are the effects of group 3 wind shear (see table 2). Due to the very small wind velocity gradients and their size from large to very large distances (several kilometers), they act so slowly and slightly on the aircraft that the accelerations are hardly perceived by passengers; the additional stresses on aircraft integrity and the very small disturbances in flight path are entirely unremarkable.

Group 2 (see table 2) wind shears can cause a sensitive reaction in the aircraft's flight path. Wind shear of this type can occur at all altitudes. Its principle effects are independent of the flight altitude for a given type and intensity of shear and a given aircraft, but with regard to the danger of their effects,

the altitude (and also in other danger modes, e.g. in rolls) plays an important role. Their danger is greatest near the ground, since the possibility of correcting the flight path is low, and this danger decreases with altitude. At altitudes over 500 m, wind shear is not an acute danger, but this does not mean that no measures are needed to compensate for disturgbances in flight path. Thus wind shear is of importance especially in take-offs and landings. In severe aircraft accidents when wind shear was the primary cause, the shear layers were all at altitudes below 250 m and the flight times within the shear layers were less than one minute.

4. Conclusions

Learning the terms and definitions of wind shear, their classification and familiarization with their properties is a necessary prerequisite for understanding their effects on aircraft, their parameters and necessary countermeasures, which will be discussed in the continuation of this article.

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Table 1: Classification of Wind Shear According to the Change in Wind Components along the Flight Path

Grundart 1	spezielle Art 2	Definition 3	Beispiele 4
5 Längswindscherung	6 Rückenwindscherung	14 Abnahme des Gegenwindes und/oder Zunahme des Rückenwindes	1.) Bild 5 b: Sinkflug von links nach rechts 20 2.) Bild 5 b: Steigflug von rechts nach links 21
	7 Gegenwindscherung	15 Abnahme des Rückenwindes und/oder Zunahme des Gegenwindes	1.) Bild 5 a: Horizontal-, Steig- und Sinkflug in beiden Richtungen 22 2.) Bild 5 b: Steigflug von links nach rechts 23 3.) Bild 5 b: Sinkflug von rechts nach links 24
8 Seitenwindscherung	9 Linkswindscherung	16 Abnahme des Seitenwindes von rechts und/oder Zunahme des Seitenwindes	1.) Bild 6 b: Steigflug von links nach rechts 23 2.) Bild 6 b: Sinkflug von rechts nach links 24
	10 Rechtswindscherung	17 Abnahme des Seitenwindes von links und/oder Zunahme des Seitenwindes von rechts	1.) Bild 6 a: Horizontal-, Steig- und Sinkflug in beiden Richtungen 22 2.) Bild 6 b: Sinkflug von links nach rechts 20 3.) Bild 6 b: Steigflug von rechts nach links 21
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Key: 1-basic type 2-specific type 3-definition 4-examples 5-longitudinal wind shear 6-tailwind shear 7-headwind shear 8-side-wind shear 9-left wind shear 10-right wind shear 11-vertical wind shear 12-upwind shear 13-downwind shear 14-decrease in headwind and/or increase in tailwind 15-decrease in tailwind and/or increase in headwind 16-decrease in side wind from right and/or increase in side wind 17-decrease in side wind from left and/or increase in side wind from right 18-decrease in downwind and/or increase in lift 19-decrease in lift and/or increase in downwind 20-fig. 5b: descent from left to right 21-fig.: ascent from right to left 22-fig.: horizontal, ascending and descending in both directions 23-fig.: ascent from left to right 24-fig.: descent from right to left 25-fig. 7a: horizontal, ascending and descending from right to left 26-fig. 7b: ascent in both directions 27-fig. 7a: horizontal, ascending and descending from left to right

Table 2: Classification of Wind Shear According to Wavelength and Gradient of Wind Velocity

Gruppe 1	Wellenlänge 2	Fequenz 3	Gradient 4	Länge der Scherschicht 5	Wirkung auf Flugzeug 6
1	klein bis sehr klein 7	8 hoch	9 sehr groß	klein bis sehr klein 7	16 kurzzeitige, u. U. große Lastvielfache wirken auf Festigkeitsverband und Insassen; nur geringe Beeinflussung der Flugbahn
2	mittel; in der 10 Größenordnung der Flugbahnschwingung	11 niedrig	12 mittel bis groß	13 mittel	17 große Beeinflussung der Flugbahn; nur geringe Wirkungen auf Festigkeitsverband und Insassen
3	groß bis sehr groß 14	11 niedrig	15 sehr klein	14 groß bis sehr groß	18 vernachlässigbare Beeinflussung der Flugbahn, des Festigkeitsverbandes und der Insassen

Key: 1-group 2-wavelength 3-frequency 4-gradient 5-length of shear layer 6-effect on aircraft 7-small to very small 8-high 9-very large 10-moderate; about the size of the flight path vibration 11-low 12-moderate to large 13-moderate 14-large to very large 15-very small 16-short term, sometimes large load multiples act on strength integrity and passengers; only minor effect on flight path 17-large effect on flight path; only minor effects on strength integrity and passengers 18-negligible effect on flight path, strength integrity and passengers

List of Symbols

H	Altitude, flight altitude; index to identify the horizontal component of a vector
i	Running index
L	Index for longitudinal wind
l	Length
S	Index for side wind; index for shear
s	Path
$\vec{u}$	Vector of wind velocity, wind velocity vector, wind vector
u	Magnitude of wind velocity, wind velocity
uH	Horizontal component of wind vector, horizontal wind
uL	Longitudinal wind component of wind vector, longitudinal wind
uL,S	Longitudinal wind shear, gradient of long. wind
uS	Side wind component of wind vector, side wind
uS,S	Side wind shear, gradient of side wind
uV	Vertical component of wind vector, vertical wind
uV,S	Vertical wind shear, gradient of vertical wind
V	Index to denote the vertical component of a vector
$\vec{v}$	Vector of flight velocity, flight velocity vector
vH	Horizontal component of flight velocity vector
vV	Vertical component of flight velocity vector
W	Vertical component of flight velocity vector
Xw	Wind direction, azimuth angle of wind